

**Picturing evaporation:
Learning science literacy through a particle representation**

Russell Tytler, Suzanne Peterson, Deakin University

Vaughan Prain, La Trobe University

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Abstract

Evaporation is mostly taught in primary schools through a water cycle representation. This has its limitations in explaining mechanisms and local effects such as drops drying in a closed room, condensation on cold surfaces, or how we smell liquids. In this paper we describe a classroom sequence of activities for Grade 5 students which explored the use of a particle model in conjunction with a range of representational modes, to explain evaporation phenomena. In interviews we explored with students their visual and verbal accounts of particles, modelling a process of teacher-mediated negotiation of multiple representations. From the evidence, we argue that difficulties in understanding evaporation are inherently representational, and that by engaging with the multiple literacies of science teachers can support significant advances in conceptual learning.

Introduction

Over the last twenty years there has been considerable research interest in students' conceptions, their nature, and the difficulties in achieving change towards scientific conceptions (Duit, 2002). A number of studies have focused on these issues in respect to teaching and learning about evaporation, (Osborne & Cosgrove, 1983; Russell, Harlen & Watt, 1989; Bar & Galili, 1994; Tytler, 2000). Some of this research has described a broad sequence of conceptualisations through which students pass, over primary and early secondary school, from notions of water 'just drying up', to 'soaking in', to 'going up to the clouds', and culminating with more sophisticated ideas about water existing in the air, involving a change of state. A number of studies have explored teaching and learning sequences in evaporation (Costa, 1994; Russell & McGuigan, 2001), based on models of conceptual change ideas drawing on this strong conceptual framing of the learning process. Other research, including our own (Tytler & Peterson, 2001; 2004) has demonstrated how the process of learning is much more complex than this, with students entertaining quite different ideas depending on the particular phenomenon, the social context, and framing their learning strongly within their own 'narratives of self' which includes their view of themselves as students and learners, and their preferences for types of explanation.

However, more recent perspectives frame learning in terms of the literacies of science, rather than thinking of it simply in terms of what goes on conceptually in individuals' heads. There is growing recognition in science education research that science as a discourse is a mix of languages entailing multi-modal forms of representation, where linguistic, numerical, and graphic and tabular modes are integrated to represent scientific explanations (Lemke, 2001, 2004; Russell & McGuigan, 2001; Unsworth, 2001). This implies that learning science effectively entails understanding different representations of science concepts and processes, being able to translate these into one another, and understanding their co-ordinated use in representing scientific knowledge. To develop a scientific literacy students need to be able to interpret and construct science texts such as tables, graphs, diagrams and science reports (Norris & Phillips, 2003). Primary school students need to be

introduced to multiple and multi-modal representations of science concepts and be able to understand, translate and connect these representations as part of learning the nature of scientific knowledge, inquiry, and reporting. 'Multiple' representations refers to the capacity of science discourse to represent the same concept or process in different modes, while 'multi-modal' representation refers to the integration of different modes to represent scientific processes, findings, and explanations. In summary, these new accounts of the nature of learning science, and factors affecting this learning, imply the need for teachers to focus on more than cognitive factors in teaching the topic of evaporation. This explicit focus on the literacies of science underpins a new Australian program 'Primary Connections' (Australian Academy of Science 2005) which has been developed with cooperation from each state.

In planning to work with grade 5 teachers on an evaporation unit, we chose to explore the use of a particle representation of the evaporative process, in helping students come to a richer understanding. The intention in introducing particle representations was to provide students with a way to a) make connections across different states of matter in the evaporative process, b) imagine how water can exist in air, and c) understand the various associated effects of the evaporative process. The students were expected to develop an understanding of evaporation through interpreting, constructing, and integrating various representational modes such as diagrams, verbal accounts, gestures, and captioned drawings.

We were aware of research that describes difficulties in students' understanding of a particle model (Driver, 1985), mainly related to the abstractness of the idea, following Piaget (1930, 1970). However, there is also research that advocates its early introduction as a powerful representation that helps students visualise phenomena (Novak, 2005). We planned to explore how negotiation of visual particle representations (in this case drawings) could help students advance their explanations.

Research questions and design

In this paper we analyse students' engagement in the classroom program and subsequent interviews to explore the following questions:

1. What representational challenges do students experience in engaging with particle accounts of evaporation?
2. In what ways can focusing on representational issues support students' conceptual learning?
3. What are the implications for teachers' understandings of students learning science, and for classroom practice?

This study used a qualitative methodology (Denzin & Lincoln 1995) involving analysis of a lesson sequence on evaporation with three grade 5 classes (age 11) in a primary school in Melbourne, followed by interviews with nine of the students. A sequence of classroom activities involving a range of evaporative phenomena was planned in which students' ideas were probed and challenged as an essential part of the learning process. The sequence followed a broadly 'conceptual change' model (Tytler, 2002; Hubber and Tytler, 2004a) which might be characterised as a '5E' sequence (engagement, exploration, explanation, extension, evaluation: Australian Academy of Science: Primary Connections). The activities were drawn from our previous work with teachers and classrooms, and can be found in Hubber and Tytler (2004b). Students were asked to interpret these through captioned drawings, gestures, and verbal explanation, and to integrate these representations. As part of this sequence a molecular model was introduced as a potential representational resource and explanatory framework, and classroom discussion focused on using this to interpret the activities.

In follow up interviews, 9 students were presented with a variation of these activities and asked to represent them in different modalities. They were challenged by the interviewer to elaborate and refine these representations and their conceptual meaning. Transcripts of the interviews were analysed to explore the way in which different students negotiated representational meaning to advance their understandings of the topic.

The classroom program

At the start of the sequence students filled in a questionnaire, using drawings and annotations, concerning their explanations of why water in a fish tank goes down, what happens to water in a puddle, what happens to sugar that dissolves, and why water might appear on the sides of a can with ice water put in it (for details on this and other activities, and discussion of the science involved, see Costa (1994) or Hubber & Tytler (2004b).

We, as the researchers, conducted a lesson in each of the three classrooms. This consisted of a whole class orientation activity in which students watched a frying pan of water boil, drawing 8 stages in the process, as signalled by a worksheet with 8 blank boxes to be filled, and annotating their drawings. A discussion on what was happening ensued. Following this, one of us presented the class with a model consisting of plastic beads in a perspex tray, which was used as the basis of a discussion on evaporation involving molecules of water breaking free of the surface and going into the air. A drawing was then constructed, during class discussion, which depicted water boiling in terms of molecules of water changing to a gas (spread out molecules) in the bubbles. The molecular model was presented as a scientific idea the students might find useful in thinking about these phenomena, and the language used was relatively open so students would not feel they were being presented with 'one true perspective'. The discussion attempted to model the productive interplay that can occur between different representations: pictorial, physical, verbal and gestural.

Following this discussion students worked in groups on three successive activities representing different evaporative contexts, for which they were encouraged to use the idea of molecules in their explanations:

- A 'cold can' activity in which ice was put in an aluminium can which was then closed. Students observed and attempted to explain the fog that appeared on the outside of the can.
- A 'disappearing handprint' activity in which students wet their hands and created a wet handprint on a chalkboard. They drew around the damp outline with chalk. As the water evaporated they were asked to explain what was happening.
- As a class activity, a bottle of eucalyptus oil was opened at the front of the room. Students were asked to put their hands up when they first smelt the eucalyptus so that the pattern of distribution of the eucalyptus vapour was tracked. This was not as straightforward as might have been expected.

For each of these activities students were asked to write on a worksheet an explanation of what happened.

Over the following two weeks, the classroom teachers ran evaporation activities using notes and worksheets we had supplied. There was no observation of these lessons but all were undertaken. The lessons were:

- A jug of water was kept in the classroom and the level of water tracked.
- A puddle was created in the school ground and its evaporation observed. Students were asked, in the worksheet, to "imagine you could take a really powerful microscope and look close up at what is happening at the edge of the puddle as it dries up. Can you draw and describe what you would see happening?" They were thus cued into a molecular representation.
- An investigation was conducted into the speed of drying of different wet cloths, in different conditions.

Following this, nine students who are part of a longitudinal study (Tytler & Peterson, 2005) were interviewed individually concerning their views of evaporation, among other things. As noted elsewhere (Tytler & Peterson, 2004), the students often embedded their engagement with and understandings of a topic in rich, personal narratives. After the program the students were asked evaporation questions related to their interpretation of the sequence based on their written responses to the worksheets, and probing their views concerning the evaporation of a drop of alcohol, placed on a glass slide, and also on a silk cloth. They were asked to

draw, as if through a powerful microscope, what was happening to the alcohol drop on the slide, and also to represent in a drawing 'where is the alcohol now?'

The scientific account of evaporation is highly spatial and visual, drawing on notions of molecular movement, spatial rearrangement, and distribution in air. It thus offered an opportunity to look more closely at the relationship between these different representational modes and the issues involved in translating between them.

Findings

The students' responses during the sequence will not be considered in detail in this paper. However, a number of points arose during the first lesson, and from worksheet responses, that are an interesting backdrop to the interviews. The views expressed were broadly consistent with conceptions of evaporation previously reported in the literature.

In the first boiling water activity the students observed the boiling process closely. Mostly they felt there was air in the bubbles, rather than steam, a misconception that has been reported in the literature (eg. Johnson 1998). They did not tend to use the particle idea to explain the activities. In the discussion of the wet handprint they tended to view the water as 'soaking in'. In the cold can condensation activity very few students talked of water from the outside air being responsible. For most, it was either a matter of leakage of water, or seepage of cold through the can causing fog.

Students' ideas in the interviews

In the interviews, a drop of alcohol was put on a slide and subsequently evaporated. Students were asked to represent on a worksheet what had happened to the alcohol and where they thought the alcohol was now. The interviewer then probed what they meant by the drawings (including the annotated drawing of the puddle they had generated in class) and challenged them to produce a coherent explanation between what they said, experienced, and what they had drawn.

*** Insert Figures 1, 2 & 3 about here

A number of students implanted the molecular idea within a water cycle notion, with varying degrees of sophistication (Figures 1, 2 and 3). In representing the mechanism of evaporation, Calum, like many students, drew the drop as consisting of many particles, gradually diminishing. In his puddle drawing he represented this as a time lapse sequence (Figure 4) and annotated the drawing with a description of the mechanism: "The heat makes the monacles (sic) jump into the air the hot air rises and takes the monacles with it ... to the clouds". Calum had also used the idea to explain condensation on a cold can: "the ice is cold on the inside and the monacles (sic) on the outside are warmer. The hot monacles are sucked to the cold and the monacles gather". Rae, in discussing the alcohol drop, talked of it 'soaking in' and then 'drying up' but when challenged to use a particle representation advanced her thinking by describing alcohol particles 'going up'.

*** Insert Figure 4 about here

One of the challenges we posed during the interview was for students to explain how the smell of the alcohol permeated the room, to potentially develop a representation of a distribution of alcohol molecules in the air. Rae did not take up this challenge but rather talked of and represented the alcohol smell 'wafting' to a nose drawn on the worksheet. When challenged to explain how others might also smell the alcohol she drew other wafting patterns to each nose in turn, indicating a tendency to think of a direct causal link between the alcohol and each nose through these waftings, rather than a sense of molecular distribution (Figure 5). She explained: "if it goes one way, all the noses over here would get it (Rae draws wafted line to nose at left of picture) and it might go a little bit over here, so they will smell it first".

*** Insert Figure 5 about here

Calum, on the other hand, shifted during the interview conversation from a view of the alcohol rising to the ceiling, to a view of the alcohol distributed throughout the room. This change was achieved by a process of the interviewer simply asking for clarification using the drawing:

Picturing evaporation

C: Ah, yeah, it would spread out and kind of ...'cause otherwise if it just went up like, eventually when it was up near the roof it would be kind of be like just lumped together and that's not what really happens. So it kind of just all spreads out.

and then drawing a nose and asking Calum to "draw in order to show that person smelling the alcohol".

C: Well all the molecules would go around and float around the room and saturate the room and when it comes past you, you can smell it

Figure 6 shows the final representation. Calum has coordinated his visual account with his verbal narrative explanation, matching these with evidence from his experience of smelling. This has been achieved by a focus on the representation.

*** Insert Figures 6 & 7 about here

Karen in her drawing (Figure 7) originally drew a little cluster of dots in one part of the room. She was challenged on this, again using a nose, and drew representative clusters ("They'd be everywhere, wouldn't they?"). She linked the molecules with what she remembered about breathing.

K: Well, when you breathe in ... the little molecules go...and then you actually smell them.....'cause they're not exactly air, and then you breath them out as carbon dioxide kind of... (The molecules would) come closer to you every time you breathed in, because the air would suck...

With these students, the process of clarification, challenge, and negotiation of explanations using the drawing was very productive in encouraging a more comprehensive explanation across visual and verbal modes.

Discussion: students' learning

The evidence from these drawings, annotations and verbal accounts shows the range of ideas that students had concerning evaporation, and their interpretation of the ideas of molecules and their distribution. Some students simply implanted the idea into a water cycle notion without exploring further the explanatory potential of the representation (Rae, Rosy), while others such as Calum and Karen developed new ways of looking at evaporation using the idea of molecules and their distribution. Calum in particular extended the idea to generate an explanation of a mechanism involving heat, and added his own representation of a time sequence. Students in the interviews showed differing preferences for visual, verbal or gestural modes, and differing extents to which they were flexible in refining and coordinating their verbal and visual representations to produce a rich explanatory narrative.

The process in the interviews of clarifying, challenging and negotiating these representations had two effects: all the students interviewed advanced in their thinking about the distribution of molecules in explaining the alcohol smell, and their developing drawings, annotations and verbal accounts provided insight into their thinking about such things as the alcohol distribution, the nature of the causal links they were making, and the way they envisaged the molecules and how this related to smell. In a class, this process of negotiation of representations would provide further possibility for refining students' ideas.

The visual nature of the representation of particles in the air was particularly helpful for students to imagine the way alcohol or water could exist in air and be distributed around the room. Calum and Karen, in the examples above, moved their explanations from a localised concern with the interaction of particles with a particular nose to a sense of random distribution that could explain the smell throughout the room. The development of these explanations of evaporation and condensation that deal with the location and distribution of water in air and the process of changing from liquid to gas state and back is a next step beyond more generalised water cycle representations.

The generation and refinement of representations (in this case mainly verbal and visual) is a key element of learning and doing science. These processes and products constitute key literacies of science, and learning to know and to do science involves their mastery and

coordination. This represents a much more significant sense of the link between literacy and science than simply learning to read stories about science or write reports of science activities.

Implications for classroom practice

There is a number of implications for classroom practice that flow from these findings, and which are consistent with a growing literature on science and literacy links. The first is that students respond differently to representations and will interpret and work with representations as tools for thinking, in different ways. Thus Calum focuses on a sense of the mechanism in extending and refining the molecular representation, and Karen focuses on an essentially verbal narrative of smell and chemical change. There are many individual ways in which a representation can be explored and applied, and classroom pedagogies need to recognise this by supporting students to engage with a rich range of representations in a way that allows them the opportunity to explore and negotiate their meaning. These representations need to be viewed as tools for thinking, rather than as fixed end points.

Ideas in science are not separate from their representation. Conceiving of evaporation as a change of state and water vapour as distributed in air inevitably involves representation, and learning about evaporation involves exploration, coordination and re-representation, refinement and negotiation of different modal representations - visual, verbal, gestural and possibly three dimensional – to generate an explanatory narrative. This study indicates that, rather than focus on science concepts as though they existed separately from representations, we need to focus explicitly in classrooms on these representations to support students to learn the rules and possibilities and interrelations between these representations. Learning the literacies of science is key to learning science.

These findings suggest rich opportunities for classroom practice, where teachers promote a representational-rich learning environment. This would involve students being challenged to make, question, explain, modify, coordinate, and justify representations as they clarify key concepts in any science topic. Such work might be negotiated in different contexts, from small-group or pair discussion to whole class investigation, perhaps incorporating diverse resources and strategies such as group posters, traditional and interactive whiteboards, computer-based programs, role plays, and digital cameras. While this study has focused mainly on challenges associated with two-dimensional representations and re-representations, this work may take many forms including physical models, role plays, and demonstrations. Many teachers are aware of these representational issues and foreground them in their teaching and learning programs. What we wish to highlight here is less well recognised point that constructing and refining representations is a core knowledge-construction activity within science, and should therefore be a major emphasis in the science classroom.

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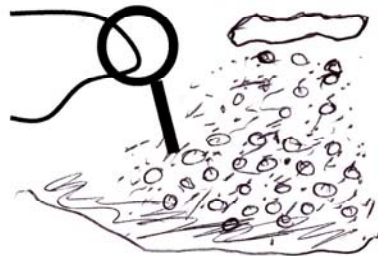
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Figure 1: Rae's drawing of the puddle evaporating

Imagine you could take a really really powerful microscope and look close up at what is happening at the edge of the puddle as it dries up. Can you draw and describe what you would see happening?



molecules of water float up to clouds to create rain inside the cloud

Figure 2: Amy's evaporating puddle

Imagine you could take a really really powerful microscope and look close up at what is happening at the edge of the puddle as it dries up. Can you draw and describe what you would see happening?

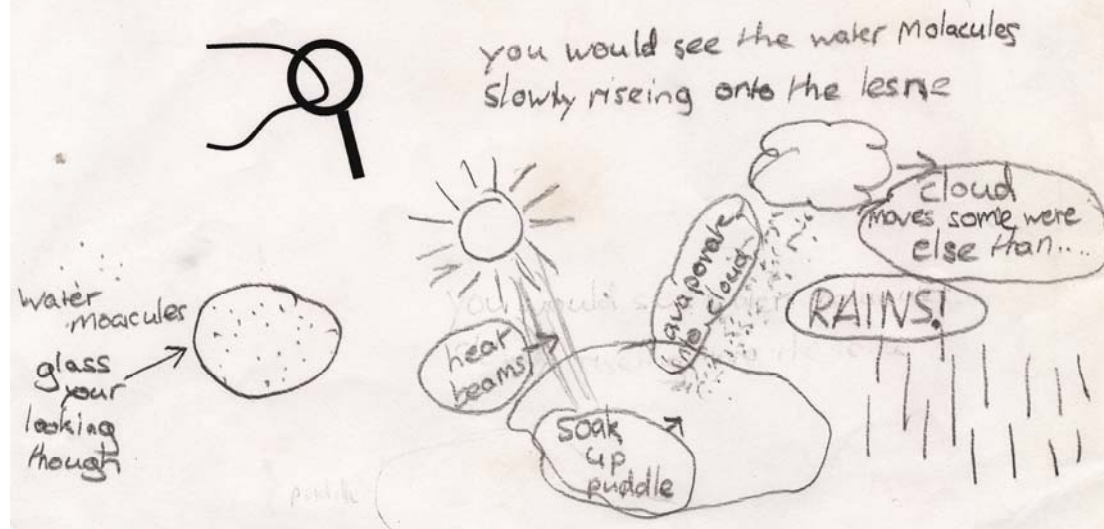
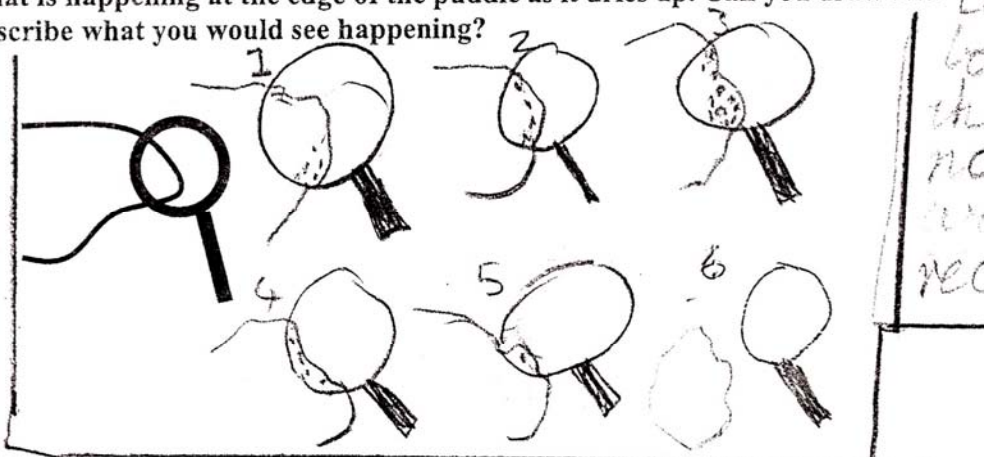


Figure 4: Calum's evaporating puddle representation

Imagine you could take a really really powerful microscope and look close up at what is happening at the edge of the puddle as it dries up. Can you draw and describe what you would see happening?



Picturing evaporation

Figure 3: Rosy's evaporating alcohol drawing

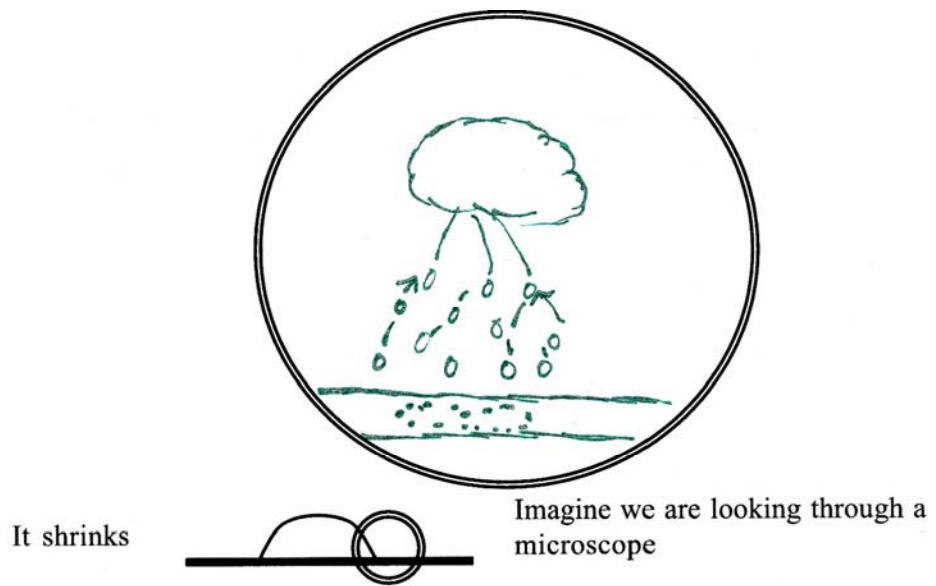


Figure 5: Rae's drawing of where the alcohol is

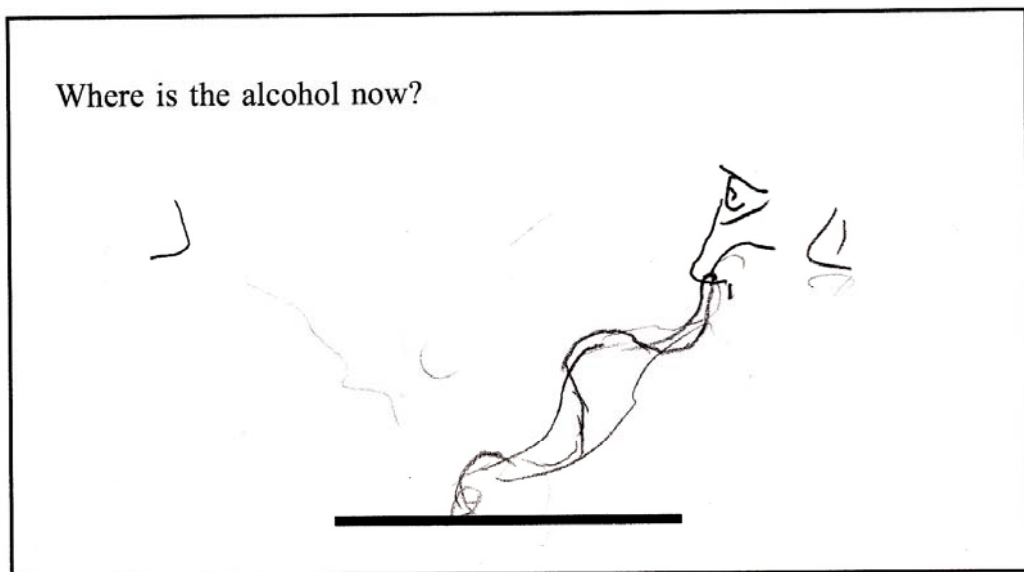


Figure 6: Calum's drawing of where the alcohol is

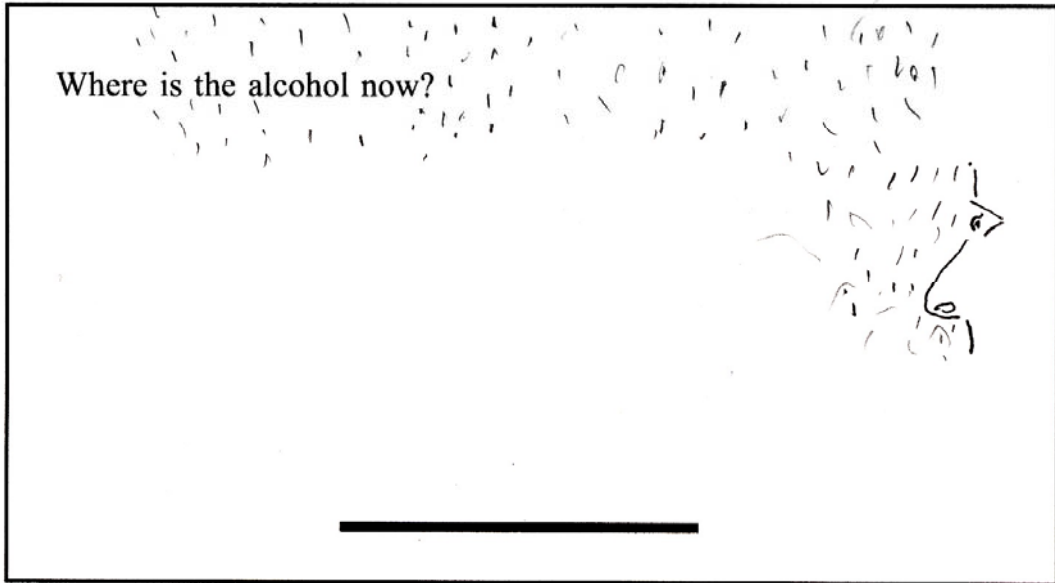


Figure 7: Karen's drawing of the alcohol

